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ABSTRACT

Mathematical techniques are developed for studying psychological problems in three fields: (1) psychological scaling, (2) learning and concept formation, and (3) mental measurement. Psychological scaling procedures are demonstrated to be useful in many areas, ranging from sensory discrimination of physical stimuli, such as colors, sounds, etc., through more complex stimuli, such as abstract qualities and concepts, including those involved in job preferences and optimality judgments. Learning and concept formation studies are concerned with the relative effectiveness of different procedures, with developing and testing different theoretical learning formulations, and with the estimation of parameters of learning curves to give more meaningful analyses of learning data. Work in mental measurement is concerned with development of better measurement procedures and with new tests for abilities, such as concept formation and creativity. Several factor analytic studies of mental ability and learning measures establish that abilities are involved in learning tasks that are different from those measured by aptitude and achievement tests. (Author/LH)

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FINAL REPORT
OF
RESEARCH ON
MATHEMATICAL TECHNIQUES IN PSYCHOLOGY
by
Harold Gulliksen

Princeton University and Educational Testing Service

June 1971

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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Personnel and Training Research Programs (Code 458) Office of Naval Research	
13. ABSTRACT 800 North Quincy Street Arlington, Virginia 22217 The research work under the project has focused on the development of mathematical techniques for studying psychological problems. These methods have been mainly related to three fields of psychology: (1) psychological scaling, (2) learning and concept formation, and (3) mental measurement. Psychological scaling procedures have been demonstrated to be useful in a great many areas, ranging from sensory discrimination of physical stimuli, such as colors, sounds, etc., through more complex stimuli, such as abstract qualities and concepts including those involved in job preferences and optimality judgments. Learning and concept formation studies have been concerned with the relative effectiveness of different procedures, with developing and testing different theoretical learning formulations, and with the estimation of parameters of learning curves to give more meaningful analyses of learning data. Work in mental measurement has been concerned with development of better measurement procedures and with new tests for abilities, such as concept formation and creativity. Several factor analytic studies of mental ability and learning measures have established that abilities are involved in learning tasks that are different from those measured by aptitude and achievement tests.			

14	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	psychological scaling						
	learning						
	concept formation						
	mental measurement						
	sensory discrimination						
	optimality judgments						
	parameters of learning curves						
	creativity						
	computer programs						
	mathematical psychology						
	attitude measurement						
	factor analysis						

The project "Mathematical Techniques in Psychology" was supported by the Office of Naval Research, Personnel and Training Research Programs, Psychological Sciences Division, under contracts N6onr 270-20 and Nonr 1858 (15) (NR 150-088), and contract N00014-67-A-0151-006 (NR 150-302). The research work under the project has focused on the development of mathematical techniques for studying psychological problems.

These methods have been mainly related to three fields of psychology: (1) psychological scaling, (2) learning and concept formation, and (3) mental measurement. Psychological scaling procedures have been demonstrated to be useful in a great many areas, ranging from sensory discrimination of physical stimuli, such as colors, sounds, etc., through more complex stimuli, such as abstract qualities and concepts including those involved in job preferences and optimality judgments. Learning and concept formation studies have been concerned with the relative effectiveness of different procedures, with developing and testing different theoretical learning formulations, and with the estimation of parameters of learning curves to give more meaningful analyses of learning data. Work in mental measurement has been concerned with development of better measurement procedures and with new tests for abilities, such as concept formation and creativity.

Several factor analytic studies of mental ability and learning measures have established that abilities are involved in learning tasks that are different from those measured by aptitude and achievement tests (see especially reports coded L,T), so that if one is interested in selecting persons for a given learning procedure, then using an appropriate learning task would probably be better than a set of tests, although it might take more time to administer. A series of scaling studies using factor analysis

has established that for any judgmental task, such as optimality judgments, a factor analysis of the data is well worthwhile to determine the different schools of thought or points of view involved, or the different attributes of the stimuli to which judges will give different weights in arriving at a decision. Evidence for this view was presented in Human Judgments and Optimality, edited by Maynard W. Shelly II and Glenn L. Bryan. Illustrations were given in a number of project reports including the recent one on "Attitudes of Different Groups Toward Work, Aims, Goals, and Activities."

The project has promoted the development of electronic computer programs suitable for analysis of data in each of the above fields, and has obtained computer programs developed in other laboratories that can be used in experiments in these fields.

During the period 1951 to 1971, when the Office of Naval Research granted funds for the project, 36 Ph.D. degrees were awarded to students who were partially supported by ONR. Of these, 32 earned the degree in the Department of Psychology, two in a bridge program including the Departments of Psychology and Mathematics, and two in the Department of Statistics.

Many of the research studies have benefited from the generous cooperation of various members of the faculty of Princeton University. A close association has been maintained between activities on this project and research activities of Educational Testing Service. Also, ETS has contributed aid in various parts of the research studies of this project, such as test construction, editing, and printing of tests and questionnaires, administration and scoring of tests, as well as use of IBM sorting, collating, and tabulating equipment to facilitate processing of the data. Many of the

project reports have also appeared as Educational Testing Service Research Bulletins.

Seventy-four experimental and theoretical research studies were conducted, 41 of which were published; 52 investigators were involved.

Technical Reports and Articles Published (1953-1971)

Code D = Dissertation
 F = Factor Analysis
 L = Learning
 M = Miscellaneous
 S = Psychological Scaling
 T = Testing and Test Theory
 X = Statistical Theory

Articles by Principal Investigator--Harold Gulliksen

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
L		
A generalization of Thurstone's learning function. (Reprints issued as TR)	May 1954	<u>Psychometrika</u> , 1953, <u>18</u> , 297-307.
S		
A least squares solu- tion for successive intervals assuming un- equal standard devia- tions. (Reprints issued as TR)	Nov. 1954	<u>Psychometrika</u> , 1954, <u>19</u> , 117-139.
S		
A least squares solu- tion for paired com- parisons with incom- plete data.	ETS RB-55-5 June 1955	<u>Psychometrika</u> , 1956, <u>21</u> , 125-134.
S		
Measurement of sub- jective values	ETS RB-55-12 July 1955	<u>Psychometrika</u> , 1956, <u>21</u> , 229-244.

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
S Comparatal dispersion, a measure of accuracy of judgment.	ETS-TR June 1957	<u>Psychometrika</u> , 1958, <u>23</u> , 137-150.
S <u>Gulliksen, H., & Tukey, J. W.</u> Reliability for the law of compara- tive judgment.	ETS-TR May 1957	<u>Psychometrika</u> , 1958, <u>23</u> , 95-110.
M Mathematical solu- tions for psycho- logical problems.	ETS-TR June 1958	<u>American Scientist</u> , 1959, <u>47</u> , 178-201. Also in D. N. Jackson and S. Messick (Eds.), <u>Problems in Human Assess- ment</u> . New York: McGraw- Hill, 1967, 3-21.
S <u>Gulliksen, H., & Messick, S. (Eds.)</u> <u>Psychological scaling: Theory and applications.</u>	June 1960	New York: Wiley, 1960.
S Linear and multi- dimensional scaling. Reprints issued as TR	June 1961	<u>Psychometrika</u> , 1961, <u>26</u> , 9-25.
L T Measurement of learn- ing and mental abilities. Reprints issued as TR	June 1961	<u>Psychometrika</u> , 1961, <u>26</u> , 93-107.
S <u>Gulliksen, H., & Tucker, L. R.</u> A general procedure for obtaining paired comparisons from multiple rank orders.	ETS-TR July 1959	<u>Psychometrika</u> , 1961, <u>26</u> , 173-183.

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
S		
Intercultural studies of attitudes.	July 1964	Chapter 3. In N. Frederiksen and H. Gulliksen (Eds.), <u>Contributions to mathematical psychology.</u> New York: Holt, Rinehart & Winston, 1964, 61-108.
S		
The structure of individual differences in optimality judg- ments.	Nov 1964	In M.W. Shelly, II, and G.L. Bryan (Eds.), <u>Human judgments and optimality.</u> New York: Wiley, 1964, 72-84.
T		
Developments in mental testing, and their re- lation to learning.		In W. Correll and Fritz Sullwold (Eds.), <u>Forschung und Erziehung: Untersuchungen zu Problemen der Pädagogik und Pädagogischen Psychologie</u> Gesamtherstellung: Ludwig Auer, Donauwörth, 1968, 156-174.
M		
Louis Leon Thurstone, experimental and mathe- matical psychologist.		<u>American Psychologist,</u> 1968, <u>23</u> , No. 11, 786-802.
M		
Methods for determining equivalence of measures.		<u>Psychological Bulletin,</u> 1968, <u>70</u> , No. 6, Part 1, 534-544.
S		
Gulliksen, H. & Gulliksen, <u>D.</u> Attitudes of different groups toward work, aims, goals, and activities.	April 1971	
L		
Learning parameters and transfer of training.		

Articles by Collaborators and Students

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,M		
<u>Abelson, R.P.</u> Spectral analysis and the study of individual differences in the performance of routine, repetitive tasks.	ETS RB-53-2 March 1953	
D,F		
<u>Kelley, H.P.</u> A factor analysis of memory ability.	ETS RB-54-7 April 1954	Memory abilities: A factor analysis. <u>Psychometric Monograph</u> <u>No. 11</u> , 1964, 51 pp.
M		
<u>Tucker, L.R.</u> A rational curve relating length of rest period and length of subsequent work period for an ergographic experiment.	ETS RB-54-4 April 1954	<u>Psychometrika</u> , 1955, <u>20</u> , 51-61.
S		
<u>Messick, S.J. & Abelson, R.P.</u> , The additive constant problem in multidimensional scaling.	ETS RB-54-13 May 1954	<u>Psychometrika</u> , 1956, <u>21</u> , 1-15.
D,S		
<u>Messick, S. J.</u> The perception of attitude relationships: A multidimensional scaling approach to the structuring of social attitudes.	ETS RB-54-27 Sept. 1954	Subsequently published as the following three articles.

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
S		
<u>Messick, S.J.</u> Some recent theoretical developments in multidimensional scaling.		<u>Educational and Psychological Measurement</u> , 1956, <u>16</u> , 82-100.
S		
<u>Messick, S.J.</u> The perception of social attitudes.		<u>Journal of Abnormal and Social Psychology</u> , 1956, <u>52</u> , 57-66.
S		
<u>Messick, S.J.</u> An empirical evaluation of multidimensional successive intervals.		<u>Psychometrika</u> , 1956, <u>21</u> , 367-375.
F		
<u>Tucker, L.R.</u> The objective definition of simple structure in linear factor analysis.	ETS RB-54-30 Nov. 1954	<u>Psychometrika</u> , 1955, <u>20</u> , 209-225.
F		
<u>Tucker, L.R.</u> Determination of parameters of a functional relation by factor analysis.	ETS RB-55-10 April 1955	<u>Psychometrika</u> , 1958, <u>23</u> , 19-23.
D,T		
<u>Keats, J.A.</u> Formal and concrete thought processes.	ETS RB-55-17 August 1955	
S		
<u>Diederich, G.W., Messick, S.J. & Tucker, L.R.</u> A general least squares solution for successive intervals.	ETS RB-55-24 Nov. 1955	<u>Psychometrika</u> , 1957, <u>22</u> , 159-173.

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
S		
<u>Messick, S.J., Tucker, L. R., & Garrison, H.W.</u> A punched card procedure for the method of succes- sive intervals.	ETS RB-55-25 Nov, 1955	A punched card method for successive intervals scaling. <u>IBM Technical News- letter</u> , No. 13, 1957, 5-14.
F		
<u>Tucker, L.R.</u> An inter- battery method of factor analysis.	ETS-TR March 1956	<u>Psychometrika</u> , 1958, <u>23</u> , 111-136.
D,F		
<u>Kline, W.E.</u> A synthesis of two factor analyses of intermediate algebra.	ETS-TR June 1956	<u>Psychometrika</u> , 1959, <u>24</u> , 343-359.
D,S		
<u>Cliff, N.</u> The relation of adverb-adjective combina- tions to their components.	ETS-TR Oct, 1956	Adverbs as multipliers <u>Psychological Review</u> , 1959, <u>66</u> , 27-44.
T		
<u>Woodbury, M. & Lord, F.</u> The most reliable com- posite with a specified true score.	Oct, 1956	<u>British Journal of Statistical Psychology</u> , 1956, <u>9</u> , Part 1, 21-28.
D,L,T		
<u>Stare, R.</u> Learning parameters, aptitudes, and achievements.	ETS-TR June 1958	<u>Psychometric Monograph</u> <u>No. 9</u> , 1961, 70 pp.
S		
<u>Helm, C.</u> A successive intervals analysis of color differences.	ETS Nov, 1960	
D,S		
<u>Morton, A.S.</u> Similarity as a determinant of friendship: A multi- dimensional study.	ETS-TR April 1959	

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,L,F		
<u>Weitzman, R.</u> A comparison of the performance of rats and fish on a probabilistic discriminative learning problem.	ETS-TR April 1959	A factor analytic method for investigating differences between groups of individual learning curves. <u>Psychometrika</u> , 1963, <u>28</u> , 69-80.
D,S		
<u>Faulds, B.</u> The perception of pitch in music.	ETS-TR May 1959	
D,S		
<u>Helm, C.</u> A multidimensional ratio scaling analysis of color relations.	ETS-TR June 1959	Multidimensional ratio scaling analysis of perceived color relations. <u>Journal of the Optical Society of America</u> , 1964, <u>54</u> , No. 2, 256-262.
D,S		
<u>Nesbitt, M.</u> Friendship, love, and values.	ETS-TR June 1959	
D,L,T		
<u>Allison, R.</u> Learning parameters and human abilities.	ETS-TR May 1960	
L,F		
<u>Tucker, L.R.</u> Determination of generalized learning curves by factor analysis.	ETS-TR July 1960	Learning theory and multivariate experiment: Illustration by determination of generalized learning curves In R.B. Cattell (Ed.), <u>Handbook of multivariate experimental psychology</u> , 1966, 476-501.
D,M		
<u>McCarter, R.E.</u> Emotional components of early recollections.	ETS-TR May 1961	

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,L		
<u>Ross, J.</u> Human memory: A partial model and its implications for retro- active phenomena.	ETS-TR May 1961	
D,S		
<u>Boldt, R.</u> The construc- tion of some judgment spaces.	ETS RB-61-18 Sept. 1961	
D,S		
<u>McGee, V.</u> The determina- tion of a perceptual space for the quality of filtered speech.	ETS RB-61-21 Dec. 1961	
D,S		
<u>Sadacca, R.</u> Dimensions of response consistency in paired comparisons.	ETS RB-62-14 May 1962	
L,F		
<u>Schepers, J.M.</u> A com- ponents analysis of a complex psychomotor learning task.	Dec. 1962	<u>Psychologia Africana</u> , 1962, 9, 294-329.
T		
<u>Woodbury, M.A.</u> The stochastic model of mental testing theory and an application.	ETS RB-62-25 Sept. 1962	<u>Psychometrika</u> , 1963, 28, 391-394.
D,S,L		
<u>Hall, A.E.</u> Concept attainment: A psycho- metric approach.		
D,T		
<u>Stafford, R.E.</u> An investi- gation of similarities in parent-child test scores for evidence of hereditary com- ponents.	ETS RB-63-11 April 1963	

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,S		
<u>Schiffman, H.</u> A mathematical analysis of the impact of the source and content on the evaluation of a message.	ETS RB-63-17 June 1963	
D,L		
<u>Carroll, J.D.</u> Functional learning: The learning of continuous functional mappings relating stimulus and response continua.	ETS RB-63-26 Sept.1963	
D,M		
<u>Brown, D.L.</u> Nonindependence in subjectively random binary sequences.	ETS RB-64-27 May 1964	
D,L		
<u>Traub, R.</u> The importance of problem heterogeneity to programmed learning.	ETS RB-64-26 May 1964	Importance of problem heterogeneity to programmed instruction. <u>Journal of Educational Psychology</u> , 1966, <u>57</u> , 54-60.
D,L,T		
<u>Duncanson, J.P.</u> Intelligence and the ability to learn.	ETS RB-64-29 June 1964	Learning and measured abilities. <u>Journal of Educational Psychology</u> , 1966, <u>57</u> , 220-229.
F		
<u>McDonald, R.P.</u> Some IBM 7090-94 programs for non-linear factor analysis.	ETS RM-65-11 August 1965	
M		
<u>Frederiksen, J.R.</u> The role of cognitive factors in the recognition of ambiguous visual stimuli.	ETS RB-65-23 July 1965	

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,L,T		
<u>Manley, M.B.</u> A factor analytic study of three types of concept attainment tasks.	ETS RB-65-31 Oct. 1965	
D,S		
<u>Lilly, R.S.</u> A developmental study of the semantic differential.	ETS RB-65-28 August 1965	
L,S		
<u>Sjöberg, L.</u> Thurstonian methods in the measurement of learning.	ETS RB-65-33 Sept. 1965	<u>Scandinavian Journal of Psychology</u> , 1965, <u>6</u> , 33-48.
D,L		
<u>Best, P.J.</u> An experimental investigation of a mathematical learning model.	ETS RB-66-15 April 1966	
D,M		
<u>Frederiksen, J.R.</u> A study of perceptual recognition in two sense modalities.	ETS RB-66-32 June 1966	Cognitive factors in the recognition of ambiguous auditory and visual stimuli. Monograph, <u>Journal of Personality and Social Psychology</u> , 1967, <u>7</u> , No.1, Part 2, 1-17.
D,S		
<u>Ramsay, J.O.</u> Some statistical considerations in multidimensional scaling.	ETS RB-66-26 June 1966	<u>Psychometrika</u> , 1969, <u>34</u> , 167-182.
D,M		
<u>Reed, S.C.</u> Some relationships between conceptual complexity and mental abilities.	ETS RB-66-33 June 1966	
D,S		
<u>Wicker, F.W.</u> A scaling study of synesthetic thinking.	ETS RB-66-25 June 1966	Mapping the intersensory regions of perceptual space. <u>American Journal of Psychology</u> , 1968, <u>81</u> , 178-188.

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,L,T		
<u>Bunderson, C.V.</u> Transfer of mental abilities at different stages of practice in the solution of con- cept problems.	ETS RB-67-20 May 1967	
D,L		
<u>Wainer, H.</u> A principal components analysis of models and men.	ETS RB-68-29 July 1968	
S		
<u>Danks, J. & Lewis, C.</u> Principal component analysis of ratings of some deviant English sentences.	ETS RB-70-12 Feb. 1970	
S		
<u>Friendly, M. & Glucksberg, S.</u> On the description of subcultural lexicons: a multidimensional approach.	May 1970	<u>Journal of Personality and Social Psychology,</u> 1970, <u>14</u> , 55-65.
D,X		
<u>Lewis, C.</u> The countback method for analyzing sen- sitivity data. (Ph.D. thesis in Department of Mathematical Statistics.)	ETS RB-70-30 May 1970	
D,X		
<u>Schlesselman, J.</u> Data transformation in two-way analysis of variance. (Ph.D. thesis in Department of Mathematical Statistics.)	ETS RB-71-33 May 1971	

<u>Title of Article</u>	<u>Date of Technical Report (TR)</u>	<u>Publication</u>
D,L		
<u>Friendly, M.</u> Proximity analysis and organization in free recall.		
D,F		
<u>Murphy, R.</u> Testing creativity in high school students.		
D,S		
<u>Tucker, W.</u> An investigation of circular triads in paired comparisons judgments.		

Electronic Computer Programs, as of May 1970

(Fortran listing available on request)

SUCNT: A Fortran IV program for the IBM 360/91 written by Carl Helm. The program provides a least squares solution for successive intervals scaling data.

PRCOMP: A Fortran IV program for the IBM 360/91 as revised by Michael Friendly. The program analyzes complete paired comparison data, with or without an absolute judgment set of data.

MULRA: The former MULRAC program revised by Michael Friendly. The program is for analysis of paired comparison type data collected by a multiple rank order design.

COMROQ: A Fortran IV program written by Michael Friendly to construct multiple rank order questionnaires. It is compatible with MULRA.

CACEYD: A Fortran IV program written by Howard Wainer for the cluster analysis of coordinates from an Eckart-Young decomposition.

TALCAM: A Fortran IV IBM program for the Tucker analysis of learning curves and more was written by Howard Wainer.

Parameter estimation in the Audley-Jonckheere learning model by least squares: A Fortran IV program for IBM 360/91 written by James Ramsay.

Continuous gradient method for obtaining maximum likelihood estimates of the parameters of the Audley-Jonckheere learning model: A Fortran IV program for the IBM 360/91 written by James Ramsay.

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Principal Investigator: Harold Gulliksen

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